Report of Geophysical Investigation

Phase I Site Characterization
Columbia Falls Aluminum Company
Columbia Falls, Montana

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Phase I Site Characterization
Columbia Falls Aluminum Company
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1.0 INTRODUCTION

A geophysical investigation was conducted by Spectrum Geophyics (Spectrum) from April 18th to April 22nd 2016, at the Columbia Falls Aluminum Company (CFAC) property located near Columbia Falls, Montana (hereinafter referred to as the Site). This work was done to assist Roux Associates in identifying the depth to groundwater, the depth to bedrock, and the depth of known landfills at the Site as part of the Phase 1 Site Characterization program for the ongoing Remedial Investigation and Feasibility Study (RI/FS). The geophysical investigation was conducted in accordance with the Geophysical Work Plan prepared by Spectrum, dated March 23, 2016. The methods used during this investigation were DC electrical resistivity and induced polarization (IP). During this survey six electrical resistivity/IP transects were established at the Site and designated as Lines 1 through 6; these transects are indicated in Figure 1. A discussion of the equipment used during this investigation is presented in Section 2.0, background is presented in Section 3.0, the methods are presented in Section 4.0, field procedures are presented in Section 5.0, data processing is presented in Section 6.0, the results and interpretation are presented in Section 7.0, and limitations are presented in Section 8.0.

2.0 EQUIPMENT

Electrical resistivity and IP field equipment consisted of the Advanced Geosciences SuperSting R8/IP system (SuperSting), passive electrodes and associated cabling. The Advanced Geosciences EarthImager® software package (AGI, 2010) was used to process the resistivity and IP data. This equipment is designed such that the data are collected in meters and then converted to feet during the data processing stage. Utility locators and a Fisher M-Scope were used to locate utilities and shallow metallic features along the designated transects.

3.0 BACKGROUND

Six transect locations were designated by Roux Associates; these transects are indicated in Figure 1.

Groundwater was known to be present at the Site, and several wells existed at the time of the survey. Based on groundwater measurements made in May of 2016 the water table was expected to be within 100 feet of the ground surface along most of the transects. Bedrock at the Site was less well determined. As stated in the RI/FS Work Plan: "Based on interpretation of the limited well logs from the Site, depth to bedrock is estimated to vary from 150 feet to greater than 300 feet across the majority of the Site depending on the proximity to the neighboring mountains and the Flathead River. In areas to the east of the Site near Teakettle Mountain, depth to bedrock is likely less than 150 ft. In the southern portion of the Site near the Flathead River, depth to bedrock may be significantly deeper than 300 feet." The lateral boundaries of the landfills were known at the time of the survey; however the depth of waste in each landfill location was not known with certainty. Based on the limited available information regarding landfill depths that was available during preparation of the RI/FS Work Plan, the estimated depth of waste materials in the five landfills located within the area of Geophysical Survey was:

- West Landfill – 65 ft below landfill surface
- Center Landfill – 15 to 20 ft
- East Landfill – 30 to 40 ft
- Wet Scrubber Pond – Unknown depth
- Sanitary Landfill – Unknown depth

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4.0 METHODS

4.1 Electrical Resistivity and IP

DC resistivity and IP were chosen for this survey as these methods are very effective in the delineation of changes in subsurface materials. In particular, these methods are sensitive to changes in grain size, changes in chemistry or mineralogy, changes in the saturation of materials, and changes in rock type. DC resistivity and IP data provide high quality, high resolution 2D imaging of subsurface layers in areas where there is a contrast in electrical resistivity and/or chargeability across an interface, such as the contrasts between dry coarse grained glacial moraine, saturated moraine, landfill materials, and metamorphic argillite rock. It is well documented that the electrical resistivity method is sensitive to changes in grain size, where coarse grained materials such as gravel and cobbles are typically higher resistivity than fine grained materials such as clay and silt. In turn, the IP method is known to be sensitive to the water table, clay and other fine grained materials, and changes in chemistry associated with landfill materials. Clays tend to have higher chargeability than sands, gravels or hard metamorphic or igneous rock; this is because clays tend to have more free ions available. By contrast, there is generally a drop in chargeability at the groundwater table. This is a phenomenon that appears to be associated with a decrease in membrane polarization.

Taken together, 2D resistivity and IP provide very powerful indicators of the nature of subsurface materials and their saturation along an established transect, and also allow discrimination between possible types of lithology giving rise to an observed geophysical response- for example, discrimination between high resistivity argillite rock and hard clay with gravel/boulders as possible sources of a high resistivity layer in the data. As such, these methods are effective for the lateral and vertical boundaries of landfill material over native material and hard rock. Therefore, both electrical resistivity and IP data were collected at the Site: electrical resistivity was used to identify the changes in lithology, and once these locations were identified with resistivity, IP was used to screen for the presence of water,clay, landfill materials, and argillite rock in these features.

The electrical resistivity and IP methods had their beginnings in the mining industry, but are now commonly used in the environmental and engineering businesses. In the electrical resistivity/IP methods a DC circuit is established in the ground via cables and electrodes, and the ground acts as the resistor to complete the circuit. There are several different arrays that can be used to collect the data; however, the most common are Wenner, Schlumberger and dipole-dipole. Electrical resistivity/IP data are typically displayed in 2D sections or profiles where they supply lateral and vertical electrical resistivity/ chargeability information about materials directly below a given established transect (much like a road cut).

4.1.1 Electrical Resistivity/IP Measurement

The electrical resistivity of a material is a measure of the ease with which an electrical current can flow through that material; whereas the IP chargeability of a material is a measure of its ability to polarize, or hold charge, after current has been applied. During a SuperSting resistivity/IP survey a known amount of current is introduced into the ground through two electrodes (current electrodes). This current then travels through the ground and the electrical potential is measured by 2 other electrodes some distance from the current electrodes. Ohm's Law (V=IR) is then used to calculate the apparent resistivity of the ground through which the current has traveled, and time domain IP methods are used to calculate apparent chargeability. This is done by determining the change in voltage from the starting voltage (in mV/V or chargeability) at specific time gates after the current has been turned off during a specified integration time (2 seconds for this project).

The SuperSting is a system that allows automated acquisition of electrical resistivity and IP data. During a SuperSting survey, many apparent resistivity/apparent chargeability measurements are made for a suite of electrode pair separations, and these apparent resistivity/ chargeability values are plotted on two-dimensional diagrams (location of measurement vs. depth). The result is two 2D subsurface images (one for resistivity and one for IP chargeability) that contain both sounding and profiling data. The automated resistivity/IP data acquisition provided by the SuperSting allows for a tremendous amount of data to be acquired relatively quickly at very high-resolution capability. Once the data have been acquired for a given transect, they can be downloaded to a field computer and subsequently viewed, color-contoured, and interpreted for features of interest.

4.2 Utility Locators

Utility locators and shallow metal detectors were used to delineate metallic/conductive utilities in the immediate vicinity of the established resistivity/IP transects in order to distinguish anomalies caused by utilities from those caused by features of interest.

Utility locators such as the Dynatel 500A (Dynatel) and Radiodetection 4000 (RD4000) are specifically designed to accurately locate and delineate metallic or conductive underground pipes and utilities. These locators are designed to detect the magnetic field resulting from an electric current flow on a line. During the use of a locator, a transmitter emits a radio-frequency source signal that induces a secondary electromagnetic field in nearby utilities. A receiver unit measures the signal strength of this secondary magnetic field and emits an audible response to allow the precise location and tracing of the pipe, cable, or other conductor in which the signal is induced. If the utility is accessible, the source signal can be directly connected to it, which makes the secondary field much larger and more readily measurable. Where no direct connection is possible, the Dynatel and RD 4000 can be used to inductively trace the pipe or cable. Utility locators are effective for the location of long, linear metallic objects.

The Fisher M-Scope (M-Scope) was used to augment the investigation of metallic utilities and to locate shallow buried metallic features (such as buried manholes) at the Site. The M-Scope has a transmitter and a receiver at the ends of a short boom. The transmitter emits a radio-frequency source signal that induces a secondary magnetic field in metallic material in its immediate vicinity. The receiver measures the signal strength of this secondary magnetic field and emits an audible response, the volume and pitch of which increase in the presence of metallic material. The sensitivity of the M-Scope allows the precise identification of the lateral boundaries of a metallic object.

5.0 FIELD PROCEDURES

5.1 Site Preparation

Lines 1 through 6 were designated by Roux Associates and established by the geophysics crew using a survey chain and surveyor's chalk; these transect locations are indicated in Figure 1.

Line 1 was 540 ground meters (1771.6 ground feet) in length and ran southwest-northeast in the southwestern portion of the Site; the northeast end of Line 1 terminated at the Northwest Percolation Pond. Line 2 was 460 ground meters (1509 ground feet) in length and ran southwest-northeast in the open area just west of the Main Plant. Line 3 was 550 ground meters (1804.5 ground feet) in length and ran southwest-northeast in the northeast portion of the Site; this line originated at the eastern edge of the Northeast Percolation Pond, came across the East Landfill and terminated at the northeast Site boundary. Line 4 was 550 ground meters (1804.5 ground feet) in length and ran southeast-northwest in the northeast portion of the Site; this line originated east of the Northeast Percolation Pond and came across the Wet Scrubber Sludge Pond and the West Landfill. Line 5 was 500 ground meters (1640.4 ground feet) in length and ran southwest-northeast in the northeast portion of the Site; this line came across the Wet Scrubber Sludge Pond and the Center Landfill, and terminated at the Cedar Creek Reservoir Overflow. Line 6 was 450 ground meters (1476.4

ground feet) in length and ran southwest-northeast in the northeast portion of the Site; this line came across the West Landfill and the Sanitary Landfill. Once the transects were properly established, stations along each transect were marked with surveyor's chalk at 10 meter intervals.

5.2 Resistivity and IP Procedures

Once the transects were marked on the ground, steel stakes were established at each electrode station along each transect and, where necessary, salt water was added to the soil to improve the electrical contact between the soil and the electrode. Once the stakes were established, the resistivity cable with passive electrodes was attached to each stake with a rubber band to form the electrical circuit. Prior to data acquisition, all recommended manufacturer system tests were conducted, and relay and contact resistance tests were conducted on the electrodes to ensure electrical communication and that enough current was traveling through the ground to obtain accurate results. Contact resistances were reduced to as low as possible before any measurements were taken. Once the initial tests were performed, Schlumberger and dipole-dipole arrays of resistivity and IP data were collected along all established transects. Two readings were taken for every measurement in order to test for repeatability in the readings.

Once the data were acquired for a given transect, they were downloaded to a field computer, reviewed for quality and saved in a raw data file. Elevations were surveyed at each electrode station along each transect by the Spectrum crew; these elevations were then calculated relative to Station 0 on each line (where this station was assigned a relative elevation of 0). Subsequently, a site topography map was provided by Roux Associates, so that relative elevations could be converted to absolute MSL elevations. A detailed sketch map of known site features that could affect the measured resistivity and IP data along each transect was made by the Spectrum crew.

6.0 DATA PROCESSING

6.1 Resistivity and IP Data Processing

The data file saved for each transect was entered into the software program EarthImager® (Advanced Geosciences, Inc., 2010). This program reads the data file, which contains information such as electrode spacing, length of transect, number of repeat measurements per electrode, and type of resistivity array. Once the data are read into EarthImager® they are reviewed for indication of erroneous or noisy data using a color graphic display. Once appropriate editing has been carried out, topography information is read into the program and the data are then sorted into finite element blocks where each block is assigned an initial resistivity value. A forward modeling algorithm that uses a non-linear least squares optimization technique is used to first calculate apparent resistivity values that would be measured with the given array type for the starting model. The calculated apparent resistivity values are then compared with the measured apparent resistivity values, and the difference between the two used to adjust the model block values to produce a model that has a lower root-mean-square (RMS) error fit to the measured section. The program advances through a series of iterations until an acceptable error level is reached (usually 10% or less) for the resistivity, at which point a linear inversion of the IP data is carried out.

For each transect, the final product of the processing is two color-contoured model sections: one for resistivity and one for IP, where the final fitting error between the *calculated* pseudosection generated from the final model section and the *actual* measured pseudosection is represented as the RMS (root mean square) in percent. It should be noted that the resolution of the resisitivity/IP method decreases with increasing depth. Therefore, the finite element mesh becomes coarser with depth, providing lower resolution and a more generalized model. This tends to produce broadening and flattening along the lower boundary. The ultimate effect of this is that the data with the highest resolution and most accurate depths are found in the upper third of the model section, where the lateral resolution is approximately one-half the unit electrode separation. In terms of the data collected for this project, one-half the electrode spacing corresponds to 5 meters lateral resolution. Because two different arrays of resistivity/IP data were collected at each location and then merged together during processing, the loss in resolution was minimized during this project. where the middle of each model section can be regarded as fairly high resolution as well, due to the redundancy in measurement. The greatest limitation is in the data located in the bottom third of the model section (corresponding to the greatest detection depth), where both lateral and vertical resolution are lower than the upper two-thirds of the section.

In terms of interpretation for the lateral and vertical boundaries of the landfills encountered during this project, this means that the interpreted lateral and vertical boundaries of landfills were made from the area in the sections with the highest resolution and the greatest density of data. Despite this, it should be mentioned that horizontal boundaries between layers with sharp resistivity contrasts, such as those that might be expected between landfill materials and underlying natural materials, will be somewhat smeared in the resistivity model section because of the smoothing algorithm used to generate the final image. Therefore, the horizontal contact separating layers of different resistivity as indicated in the model section would not be expected to be an exact measurement of the base of landfill materials; rather a smoothed image of that boundary. Because of this limitation it is useful to correlate the final model section with actual drilling results for highest accuracy in interpretation.

7.0 RESULTS AND INTERPRETATION

A Geophysical Survey Location Map is presented in Figure 1. Electrical resistivity and IP profiles of the final model sections for Lines 1 through 6 are presented in Figures 2 through 7, respectively. The following sections contain a discussion of the results.

In order to facilitate discussion of resistivity values and to compare and contrast between transects, a standard resistivity color scheme (ranging from 1.0 Ohm-meters to 100,000 Ohm-meters) was created and used for all of the model resistivity profiles generated for this project. This color scheme ran from darkest blue (lowest resistivity) to darkest purple (highest resistivity). A similar standard color scheme was created for the IP chargeability values, where lowest chargeability values (-1000 to -250 milliseconds) are darkest blue and high chargeability values (200 to 650 milliseconds) ran from dark red (200 mS) to dark brown (650 mS). These standard resistivity and IP chargeability color schemes were used for the profiles in Figures 2 through 7.

It is well known that the electrical resistivity method is sensitive to changes in lithology, where in a general sense fine grained materials are lower resistivity and coarse grained materials are higher resistivity. However, site-specific lithologic interpretation of resistivity can be made much more precise with ground truth from borings or wells that lie in the vicinity of the data. For this project, resistivity interpretation was made from review of driller's logs for the previously existing wells as well as the Roux borings that had been completed at the time of the report, from on-site geologic and lithologic observations, photos, and general experience at similar sites. Based on this correlation and experience in similar environments, lithologic relationships to resistivity values obtained during this investigation were derived; a summary of these interpretations is provided in Table I.

The most important resistivity/IP correlation resulting from comparisons with Roux drilling results is that, while it was anticipated that the metamorphic bedrock would be hard and highly resistive (2500 Ohm-meters or higher), this bedrock in fact ranges in resistivity between 200 and 5,000 Ohm-meters, depending on whether it is weathered/fissile or competent (core rock). In addition, while the IP signature of bedrock was expected to be low (deep blue colors) it in fact ranges between moderate values (20 to 100 milliseconds – pink colors) to low values (blue colors). These factors make the signature of bedrock more difficult to identify because other non-bedrock materials also have this range of resistivity/IP values associated with them.

Perhaps most importantly, the highest resistivity material (up to 100,000 Ohm-meters – darkest purple) encountered during this investigation does not correspond to bedrock at all but to stiff, dry glacial till, where in several locations the extremely high resistivity till is associated with very low IP values (deep blue colors).

For the purposes of this report the assumption made for the interpretation of natural materials was that increases in resistivity correspond to either an increase in material grain size or material stiffness, dryness or hardness. In the case of changes in grain size lower resistivity values correspond to finer grained materials such as clays and silts, and higher resistivity values correspond to coarser grained materials such as gravels, cobbles and boulders. In the case of material stiffness or hardness, lower resistivity material would correspond to softer unconsolidated material, where high resistivity material would correspond to consolidated or lithified, stiff and dry material. The possibility of a decrease in resistivity representing an increase in material saturation was taken into account at depths considered to be favorable to the presence of groundwater (generally 50 feet or greater below ground surface). In addition, low resistivity values in the landfill area were considered to be associated with landfill materials, particularly where elevated IP existed in the presence of low resistivity values.

It is important to mention that the lithologic interpretation of resistivity values is *highly site specific* and depends on several factors, including depositional environment, geologic environment (i.e. sedimentary vs igneous vs metamorphic rocks), structural features such as faults, folds and fractures, mineralogical features such as the presence of crystals, salts, or other byproducts of the smelting process, degree of water saturation of materials, and natural groundwater resistivity in the study area. Therefore, interpretations that apply very well to one specific location may be *erroneous* for another location. In particular, the interpretations and relationships presented in Table I that apply to natural and landfill materials *apply specifically to this locality and geology* and should be not be applied to other locations.

In Figures 2 through 7 the upper profile contains the inverted resistivity distribution which best represents the actual lateral and vertical variation of earth resistivity beneath the ground surface along the designated transect. The lower profile contains the inverted IP chargeability distribution which best represents the actual lateral and vertical variation of earth chargeability beneath the ground surface along the designated transect. In these figures, the colors represent values which key to the color bar to the right side of the image. The numbers across the top of each model section represent ground distances along each transect in units of feet as measured from Station 0. The numbers along the vertical axis of each section are the elevations in MSL-feet, as determined from ties to bench marks provided by Roux Associates. The dashed blue line indicates the top of the saturated zone, as interpreted from comparing boring/well ties with the resistivity and IP data. The dashed black line indicates the interpreted base of landfill waste materials in areas where the depth of landfill was unknown. The queried dashed black line indicates the expected depth of landfill waste materials based on information provided by Roux Associates, and the white dashed line indicates the top of argillite bedrock where it can be confidently interpreted. The interpretations of these lines are discussed below.

7.1 Line 1

Water Table

The interpreted water table along Line 1 is identified with a dashed blue line in Figure 2. There were 3 well ties to Line 1, which were used to correlate lithology and measured water table with the resistivity and IP signatures. Based on the resistivity signature (ranging between 150 and about 600 Ohm-meters) between 0 and about 60 feet below ground surface in the southwestern portion of Line 1, the materials are interpreted as dry and coarse grained sands and gravels. The water table at the southwest end of Line 1 (up to about Station 450) is interpreted as ranging from 75 to 84 feet bgs (3032 to 3020 MSL) based on a drop in resistivity at this elevation, a tie to well TW11/CFMW-056, and a corresponding decrease (green colors) in the IP chargeability at this elevation. Based on the resistivity signature below about 84 feet bgs on Line 1, it appears that the materials below this elevation consist of saturated sand and gravel. The vertical drop in resistivity and chargeability can be observed across the section to the northeast and is interpreted as representing the groundwater table. Based on this correlation, the water table appears to shallow to the northeast, where it appears to be shallowest (20 feet bgs) at the northeast end of Line 1.

Bedrock

Based on a comparison with drilling results and resistivity/IP vaules and character, bedrock does not appear to be present within the depth of detection along Line 1 (within 440 feet of the ground surface).

7.2 Line 2

Water Table

The interpreted water table along Line 2 is identified with a dashed blue line in Figure 3. Based on the high resistivity signature (ranging between 1000 and about 2500 Ohm-meters) between 0 and about 50 feet below ground surface along Line 1, the materials are interpreted as dry and coarse grained sands and gravels. The water table is interpreted at about 53 to 60 feet bgs (3055 to 3048 MSL) between Stations 0 and at least 750. This interpretation is based on a drop in resistivity at this elevation, a corresponding decrease in the IP chargeability at this elevation, and the known water depths at wells W8/CFMW-044 and TW1/CFMW-044b. Based on the resistivity signature below about 60 feet bgs at this portion of Line 2, it appears that the materials consist of saturated sand and gravel/large gravel.

Between Stations 800 and 1450 the water table appears to rise in elevation to between 30 and 40 feet bgs, based on an observed decrease in IP chargeability between 30 and 40 feet bgs (3065 to 3074 MSL).

Bedrock

Based on a comparison with drilling results and resistivity/IP vaules and character, bedrock does not appear to be present within the depth of detection along Line 2 (within 335 feet of the ground surface).

7.3 Line 3

Water Table

The interpreted water table along Line 3 is identified with a dashed blue line in Figure 4. The water table on Line 3 was interpreted based on the tie to Line 4 and a vertical decrease in resistivity and IP chargeability at the anticipated elevation of groundwater. Based on these factors, the water table is interpreted at about 60 to 70 feet bgs (3067 to 3073 MSL) between Stations 0 and 900. Northeast of Station 900 groundwater appears to rise gradually to elevation 3090 at Station 1450, based on a decrease in resistivity and chargeability, as well as the tie to TW10/CFMW-023.

Landfill Material

Line 3 intersected the expected lateral boundaries of the East Landfill between about Station 1525 and at least Station 1775. The expected base of the East Landfill waste material along Line 3 was 30 to 40 feet; the dashed, queried black line in Figure 4 between Stations 1525 and 1775 represents a 40-foot depth of waste material. The resistivity of the material above this line ranges from moderate to high values, which alone do not seem to stand out against background materials; however, the elevated IP values in this area are consistent with the presence of waste material to at least a depth of 40 feet below the top of the landfill.

Bedrock

Bedrock was encountered by Roux Associates at a depth of 148 feet below ground surface in Well CFMW-23a (Station 1489 on Line 3). Based on this result, the resistivity and IP values were compared at the bedrock contact where CFMW-23a projects to Line 3. At the projected location the resistivity values are moderately high only and the IP values are moderate as well. This could be a result of projecting well data from a distance of 250 feet southeast of the line, where the resistivity values might suggest more highly weathered rock this precise location; although the resistivity values at this same elevation increase northeast of about Station 1575, indicating possibly more competent rock northeast of Station 1575. Because the IP values exhibit a sharp increase at the projected bedrock contact, the IP data were used to interpret top of bedrock along Line 3. Based on this, the bedrock contact was interpreted to exist between Stations 1320 and at least 1640 ranging between 200 feet and 148 feet below ground surface. This bedrock contact is indicated with a dashed white line In Figure 4.

7.4 Line 4

Water Table

The interpreted water table along Line 4 is identified with a dashed blue line in Figure 5. The water table southeast of the Wet Scrubber Sludge Pond on Line 4 was interpreted using the ties to wells W5-TW-15/CFMW-019 and W6-TW-18/CFMW-021, and by comparing the resistivity and IP signatures at the depths of known water. Based on this, the resistivity data indicate a sharp change from high resistivity to lower resistivity, while the corresponding IP data exhibit a drop in chargeability, at about elevation 3067 (68 feet below ground surface). The high resistivity material above this level is interpreted as dry coarse grained sand and gravel, whereas the material below this level is interpreted as saturated sand and gravel. As the low IP (green) horizon continues to the southeast, the water table is inferred to follow this line. A similar low IP (green) horizon occurs below the West Landfill Area at about elevation 3080; this level may be associated with groundwater, as groundwater approximately 400 feet to the southwest of Line 4 (well TW-3/CFMW-007) is at elevation 3086.

Landfill Material

The interpreted base of landfill materials along Line 4 in the Wet Scrubber Sludge Pond Area is identified with a dashed black line in Figure 5. This landfill material was interpreted based on the presence of near surface low resistivity material, and general lateral heterogeneity in the resistivity signature. Based on this, the apparent landfill thickness in the Wet Scrubber Sludge Pond Area ranges from about 15 feet (Station 585) to 38 feet (Station 735). As noted in Section 3.0 of this report the RI/FS Work Plan indicated an estimated depth of 65 ft for the West Landfill. This depth is represented by a dashed and queried black line between Stations 1000 and about Station 1560 on Line 4. An area of low resisistivity (3 to 10 Ohm-meters – blue colors) is identified at this depth between Stations 1267 and 1463, and appears to extend deeper. This suggests that the landfill may extend deeper, perhaps to a depth of 115 ft as indicated by the deep blue low resistivity layer. Alternatively, the deep blue low resistivity layer could represent an area of impacted soil or groundwater underlying the landfill.

Bedrock

There were no wells or borings in the vicinity of Line 4 that indicated bedrock. The tie location to Line 5 was used as a point of comparison to determine if similar material existed on Line 4 as that on Line 5 at the tie point. While at first the extremely high resistivity material (dark purple) along Line 4 beginning at about Station 550 at about 100 feet below ground surface (3060 MSL) was thought to represent hard bedrock, this material is now interpreted to be stiff, dry glacial till based on Roux drilling ties to high resistivity on Lines 5 and 6. Because this high to extremely high resistivity extends to depth and to the northwest on Line 4, and because it has areas of extremely low IP which appears to be associated with the stiff, dry glacial till encountered during Roux drilling, bedrock does not appear to be present within the depth of investigation (400 feet below ground surface or above elevation 2800) on Line 4.

7.5 Line 5

Water Table

The interpreted water table along Line 5 is identified with a dashed blue line in Figure 6. The water table southwest of and beneath the Wet Scrubber Sludge Pond on Line 5 was interpreted using the tie to well W5-TW-15/CFMW-019, and by comparing the resistivity and IP signatures at the depths of known water. Based on this, the resistivity data indicate a sharp change from high resistivity to lower resistivity between about Stations 125 and 350, while the IP data exhibit a drop in chargeability between Stations 0 and about 800, between elevations 3060 and 3070. Therefore, the water table; the water table is inferrred to follow this line beneath the Wet Scrubber Sludge Pond to at least Station 800. The water table at the northeast end of Line 5 was interpreted using ties to wells TW8/CFMW-020 and TW14/CFMW-017. While the resistivity values do not appear to decrease at the elevation of groundwater for these wells, there is a drop in IP at the level of groundwater; therefore, an interpreted groundwater horizon has been made between about Stations 1100 and 1550 at about elevation 3100 to 3105. As neither the resistivity nor the IP values exhibit a decrease at the expected elevation of groundwater between Stations 850 and 1100, no interpretation of the water table can be made in this station range.

Landfill Material

The interpreted base of landfill material along Line 5 in the Wet Scrubber Sludge Pond Area is identified with a dashed black line in Figure 6. This landfill material was interpreted based on the presence of near surface low resistivity material, and general lateral heterogeneity in the resistivity signature.

Based on this, the apparent thickest portion of landfill material in the Wet Scrubber Sludge Pond Area occurs between Stations 540 and 673. In this area the landfill ranges in thickness from 15 to 43 feet, where it is thickest at Station 600. Between Stations 735 and 1200 the depth of the landfill material ranges between 15 and 30 feet. As noted in Section 3.0, the

RI/FS Work Plan indicated an estimated depth of 15 to 20 ft for the Center Landfill. An assumed landfill depth of 20 feet is represented by the dashed and queried black line between Stations 1355 and about Station 1540 on Line 5. An area of low resisistivity (7 to 8 Ohm-meters – blue colors) is identified at this depth between Stations 1402 and at least 1464, and appears to extend deeper. This suggests that the landfill may extend deeper, perhaps to a depth of 50 ft as indicated by the lower resistivity (green) layer. Alternatively, the green lower resistivity layer could represent an area of impacted soil or groundwater underlying the Center Landfill.

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Bedrock

None of the wells that tied to Line 5 definitively identified bedrock; although "red brick-like shale" was noted in the driller's log for TW8/CFMW-020 at about elevation 3019. At this depth the resistivity values are moderately high (1000 Ohm-meters) and the IP values are low (green) as might be expected with a hard rock contact. Although a sharp drop in IP is not observed right at the shale contact, it should be noted that the drilling information at Station 1273 is projected from 200 feet to the southeast of Line 5, and so some variability might be expected. Based on this "shale" contact, and based on the expectation that bedrock should exist at an elevation of about 3056 at the northeast end of Line 5 based on the contacts indicated in Roux wells CFMW-023 to the southeast and CFMW-008 to the northwest, the top of bedrock was interpreted between Stations 1300 and at least 1460 between the elevations of 2940 and about 3000. The top of bedrock contact is indicated with a dashed white line in Figure 6.

Because no bedrock was encountered in Roux well CFMW-016a, and because a vertical column of extremely high resistivity values occur between Stations 900 and 1200 (which is believed to be associated with stiff, dry glacial till), bedrock is not believed to exist within the depths of detection southwest of Station 1300 on Line 5.

7.6 Line 6

Water Table

The interpreted water table along Line 6 is identified with a dashed blue line in Figure 7. The water table southwest of the West Landfill and up to Station 315 on Line 6 was interpreted using the tie to well TW3/CFMW-007, and by comparing the resistivity and IP signatures at the depth of known water. Based on this, the resistivity data indicate a sharp change from high resistivity to lower resistivity between about Stations 100 and 200, while the IP data exhibit a vertical change in chargeability (in some cases an increase and in some cases a decrease) between Stations 50 and about 315, at elevation 3084. Therefore, the water table is inferrred to follow elevation 3084 between Stations 50 and 315. The water table northeast of the West Landfill was interpreted using the tie to well TW9/CFMW-008. The resistivity values exhibit a sharp change from high resistivity to low resistivity between Stations 980 and 1040 at elevation 3100. In addition, there is a general vertical drop in IP at the level of water (elevation 3100) during drilling of CFMW-008 ; therefore, an interpreted groundwater surface has been made between about Stations 950 and 1400 between elevations 3100 and 3154.

Landfill Material

Line 6 crosses both the West Landfill and the Sanitary Landfill. As noted in Section 3.0 of this report the RI/FS Work Plan indicated an estimated depth of 65 ft for the West Landfill. This depth is represented by a dashed and queried black line between Stations 280 and about Station 927 on Line 6. An area of low resisistivity (3 to 10 Ohm-meters – blue colors) is identified at this depth between Stations 365 and 609, and appears to extend to greater depths, especially between Stations 365 and 500. This suggests that the landfill may extend deeper, perhaps to a depth of 106 ft as indicated by the deep blue low resistivity layer. Alternatively, the deep blue low resistivity layer could represent an area of impacted soil or groundwater underlying the West Landfill.

The depth of waste materials at the Sanitary Landfill was unknown. The interpreted base of waste materials in the Sanitary Landfill along Line 6 is identified with a dashed black line in Figure 7 between Stations 1100 and 1300. This landfill material was interpreted based on the presence of lower resistivity near surface material and general lateral heterogeneity in the resistivity signature. Based on these factors the depth of waste material in the Sanitary Landfill ranges between 18 feet and 55 feet, where it is thickest at Station 1200.

Bedrock

Bedrock was encountered by Roux Associates at a depth of 150 feet below ground surface in Well CFMW-008 (Station 1088 on Line 6). Based on this result, the resistivity and IP values were compared at the bedrock contact where CFMW-008 projects to Line 6. At the projected location the resistivity values are moderately high only and the IP values are moderate as well. This could be a result of projecting well data from a distance of 260 feet southeast of the line, where the resitivity values might suggest more weathered rock at this precise location. Because the IP values exhibit a sharp increase at the projected bedrock contact, the IP data were used to interpret top of bedrock along Line 6. Based on this, the bedrock contact was interpreted to exist between Stations 975 and at least 1338 between elevations 2988 and 3073. This interpreted bedrock contact is indicated with a dashed white line in Figure 7.

An extremely high resistivity/ very low IP (deep blue) feature can be found between Stations 394 and about 828 between elevations 2980 and 3056. This feature is believed to be associated with stiff, dry glacial till based on correlations with Roux drilling information and the tie to Line 4. Based on this feature and the character of the resistivity/IP data southwest of Station 950, bedrock is not believed to exist within the depths of detection southwest of Station 950 on Line 6.

8.0 LIMITATIONS

This investigation was conducted in accordance with generally accepted methods and procedures followed in the industry. Although every effort was made to minimize sources of error in the data and results, each method has its limitations. In addition, the interpretation of the data, while made considering the site background information and the geologic and hydrogeologic maps for the area, was based on assumptions which may not be exactly correct. These factors are discussed below.

The location of features as depicted in Figure 1 may not be exactly correct. This is because features were measured and mapped during the investigation according to *ground distance;* whereas features depicted in Figure 1 were measured in *horizontal distance* from a satellite image. As a result, the mapped location of lateral boundaries may be in error by a few feet compared with the actual distance traversed in ground units.

8.1 Resistivity/IP Method

The lateral resolution, and accuracy, for resistivity/IP surveys is determined by data quality and electrode spacing. During this investigation the quality of the data was in general very good; however, there were some "noisy" areas where interference from the presence of utilities was observed; in particular the overhead power lines at the northeast end of the Site caused some electrical interference in the data. Because both Schlumberger and dipole-dipole data were combined in the final interpretation, it can be stated that the shortcomings of noise from utilities were effectively minimized.

9.0 REFERENCES

Loke, M.H., 1998, RES2DINV ver. 3.3: *Rapid 2D Resistivity Inversion Using the Least Squares Method*: Penang, Malaysia.

Loke, M.H., *"Tutorial: 2-D and 3-D Electrical Imaging Surveys:"* Penang, Malaysia.

Nabighian and Elliot, "Negative Induced-Polarization Effects from Layered Media", 1976, Geophysics, 41, 6A, pp. 1236-1255.

Roux Associates, 2015, "*Remedial Investigation/Feasibility Study Work Plan, Former Primary Aluminum Reduction Facility, Columbia Falls, Montana,*" prepared for Columbia Falls Aluminum Company LLC, November.

Telford, W.M., L.P. Geldart, R.E. Sherriff, and D.A. Keys, 1976, Applied Geophysics, Cambridge University Press, Cambridge, England.

TABLE I: Interpretation of Resistivity for Lithology/Material Type
Columbia Falls, Montana

Resistivity			Interpretation
Range	Color	Category	
1 to 7 ohm-meters	darkest blue to dark blue	low resistivity	landfill materials to clays: 1 Ohm-meter is highly conductive and may indicate changes in chemistry, values approaching 7 could be associated with clay
7 to 27 Ohm-meters	dark blue to light blue	low to moderately low resistivity	clay to clay with silt, sand or gravel, where values approaching 27 Ohm-meters have greater amounts of coarse grained material; alternatively these values could be associated with landfill materials
27 to 68 Ohm-meters	light green to yellow	moderately low resistivity	silt with sand to sand with silt and fine gravel, where values approaching 68 Ohm-meters have greater amounts of coarse sand and gravel; alternatively these values could be associated with landfill materials
68 to 200 Ohm-meters	orange-tan to grey to yellow-green	moderately low to mid-range resistivity	silt and gravel to coarse gravel to gravel with cobbles, where values approaching 200 Ohm-meters have greater amounts of cobbles
200 to 5,000 Ohm-meters	yellow green to tan to light pink	moderately high to high resistivity	coarse sands and gravels with cobbles or boulders; alternatively these values may be associated with weathered to hard argillite rock
5,000 to 100,000 Ohm-meters	pink to red to light purple to darkest purple	high to extremely high resistivity	Very coarse grained sands, cobbles and boulders to stiff, dry glacial till, where values over 70,000 are likely associated with stiff, dry glacial till

***NOTE: This table is provided as a brief discussion of results found. For a more detailed interpretation of data, please refer to Section 7.0 of the report

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Legend

Existing well location

Resistivity Transect

Scale is approximate (feet)

0 250 500

N W E S NORTH

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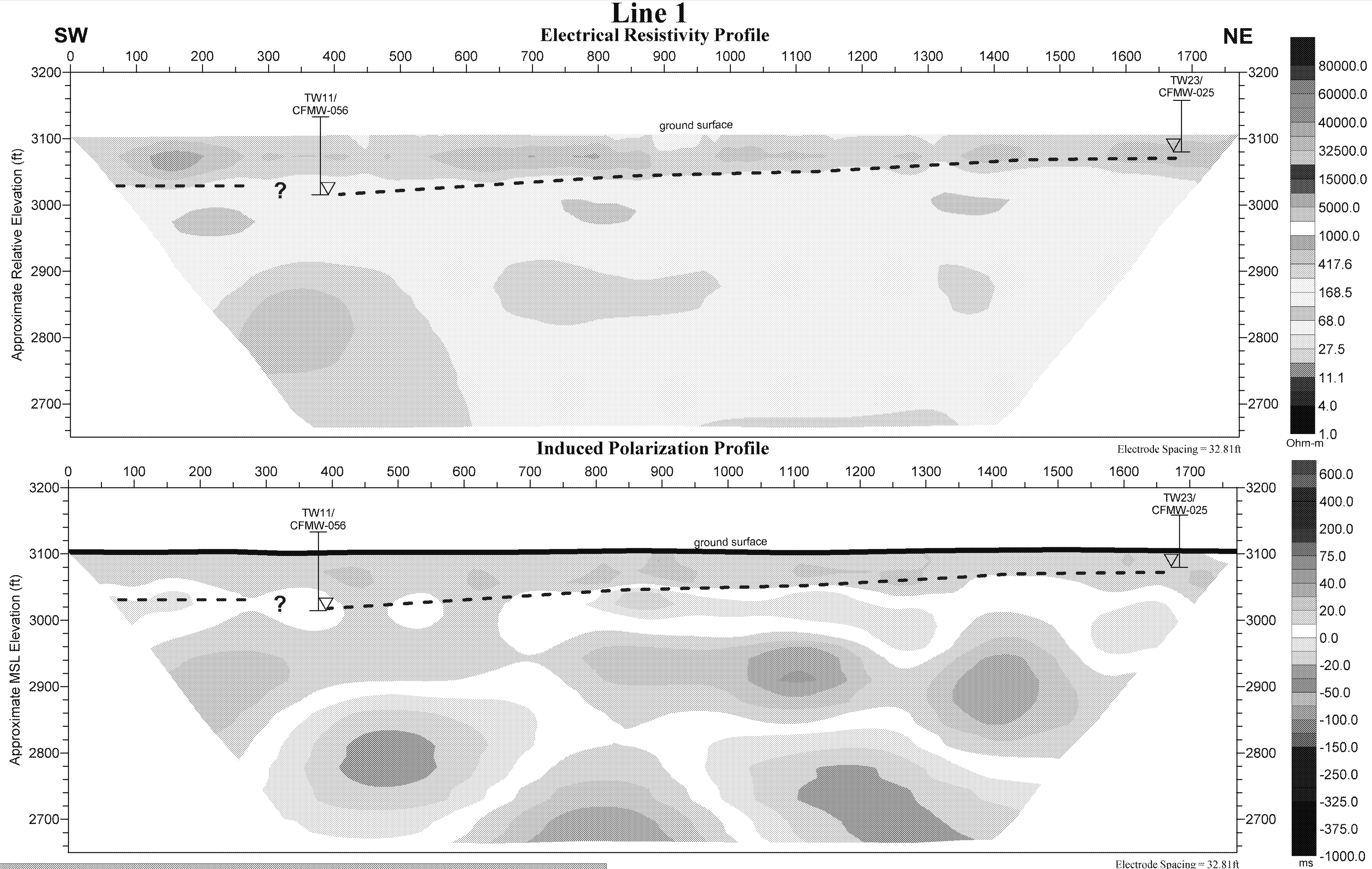
	Geophysical Survey Location Map
PROJECT	Geophysical Investigation 2000 Aluminum Drive Columbia Falls, Montana
PREPARED FOR	Roux Associates Islandia, New York
SCALE	1 inch = approximately 500 ft
FIGURE BY	BAU
REVIEWED BY	LCD
FIGURE NUMBER	1
PROJECT NUMBER	1604181L
DATE	7/20/16



Legend

- Water Table
- TD — Total depth of boring
- BD — Depth to Bedrock from drilling results
- Interpreted Base of Landfill Material
- Interpreted elevation of groundwater, queried where uncertain
- ? ? — Expected base of landfill material
- Interpreted Top of Bedrock

scale in feet: 0 — 75 — 150

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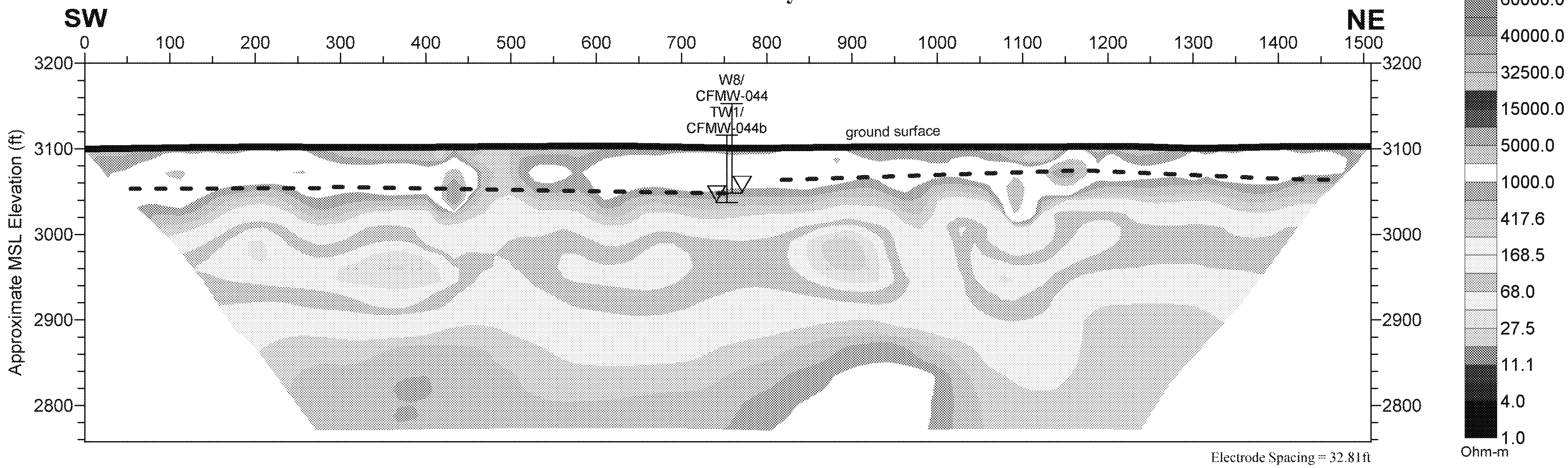
Title	Electrical Resistivity and Induced Polarization Profile - Line 1
Figure Number	2
Project	Geophysical Investigation, 2000 Aluminum Drive, Columbia Falls, Montana
Prepared For	Roux Associates, Islandia, New York
Project Number	1604181L
Scale	1 inch = 150 feet
Figure By	BAU
Reviewed By	LCD
Date	7/20/16

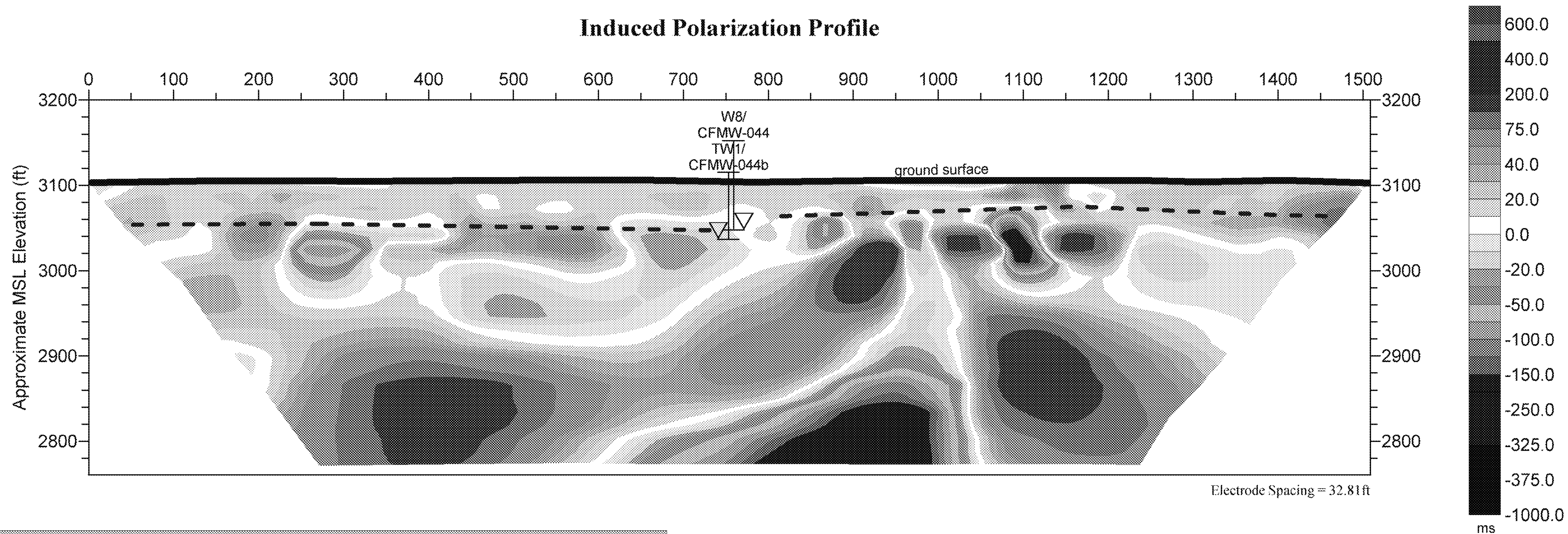
ED_002345B_00009369-00023

Line 2

Electrical Resistivity Profile



Induced Polarization Profile



Legend

- Water Table
- TD Total depth of boring
- BD Depth to Bedrock from drilling results
- Interpreted Base of Landfill Material
- Interpreted elevation of groundwater, queried where uncertain
- ? ? Expected base of landfill material
- Interpreted Top of Bedrock

scale in feet

0 75 150

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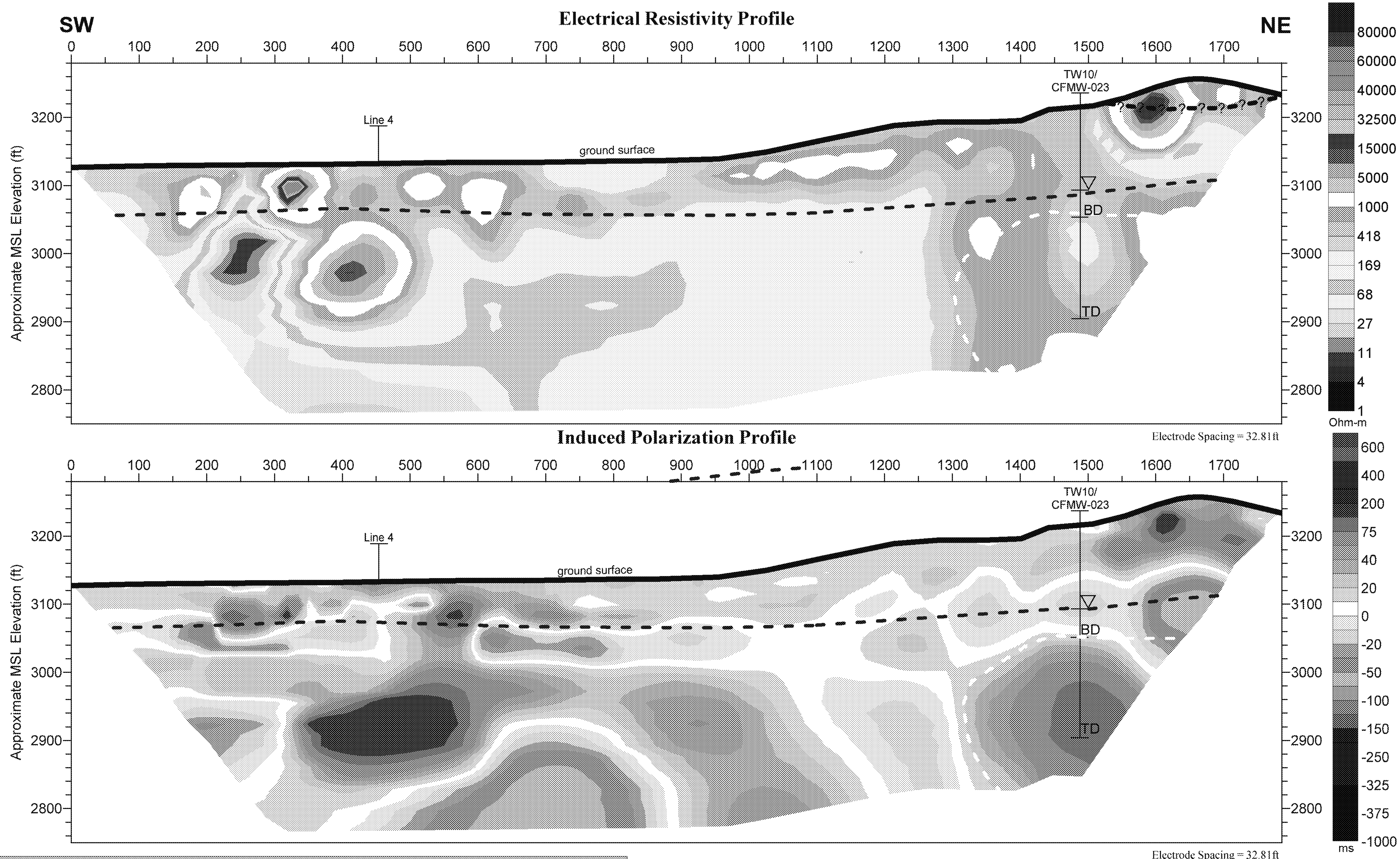
	Electrical Resistivity and Induced Polarization Profile - Line 2
FIGURE NUMBER	3
PROJECT	Geophysical Investigation 2000 Aluminum Drive Columbia Falls, Montana
PREPARED FOR	Roux Associates Islandia, New York
PROJECT NUMBER	1604181L
SCALE	1 inch = 150 feet
FIGURE BY	BAU
REVIEWED BY	LCD
DATE	7/20/16

Line 3



Legend

- Water Table
- TD — Total depth of boring
- BD — Depth to Bedrock from drilling results
- Interpreted Base of Landfill Material
- Interpreted elevation of groundwater, queried where uncertain
- ? ? Expected base of landfill material
- Interpreted Top of Bedrock

scale in feet: 0 75 150

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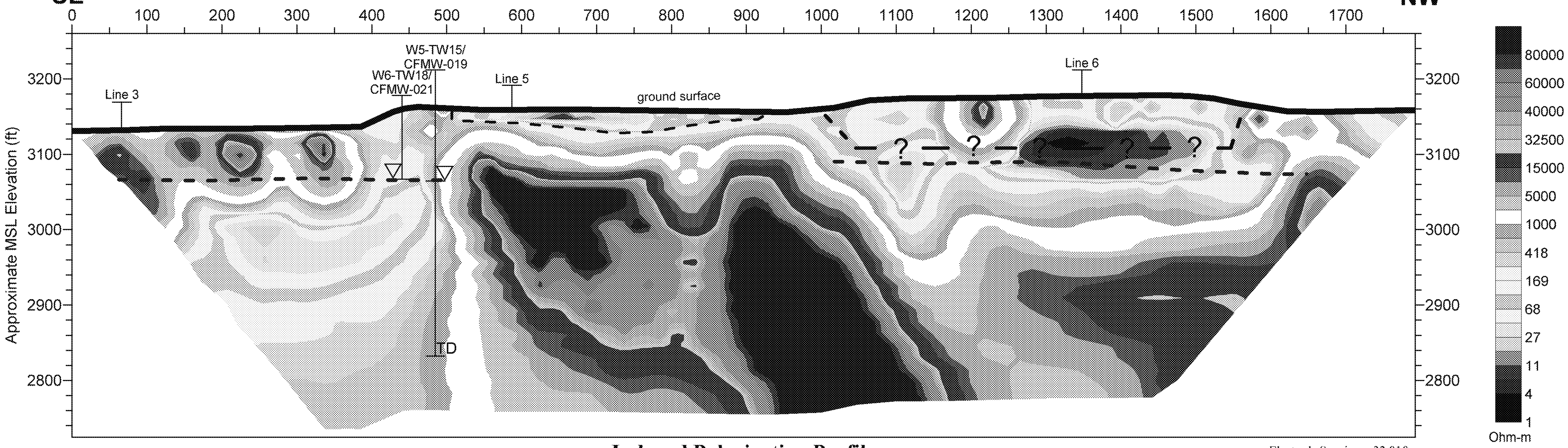
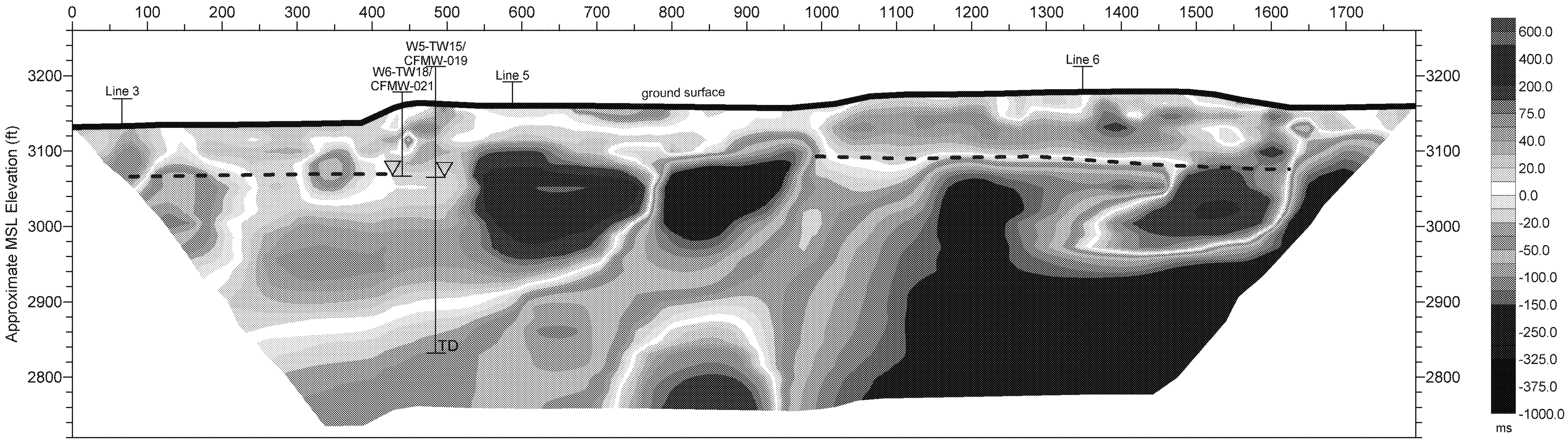
Electrical Resistivity and Induced Polarization Profile - Line 3	FIGURE NUMBER: 4
PROJECT: Geophysical Investigation, 2000 Aluminum Drive, Columbia Falls, Montana	
PREPARED FOR: Roux Associates, Islandia, New York	PROJECT NUMBER: 1604181L
SCALE: 1 inch = 150 feet; FIGURE BY: BAU; REVIEWED BY: LCD	DATE: 7/20/16

Line 4

Electrical Resistivity Profile



Induced Polarization Profile



Legend

▽	Water Table
TD	Total depth of boring
BD	Depth to Bedrock from drilling results
— — —	Interpreted Base of Landfill Material
— — —	Interpreted elevation of groundwater, queried where uncertain
— ? — ?	Expected base of landfill material
- - -	Interpreted Top of Bedrock

scale in feet

0 75 150

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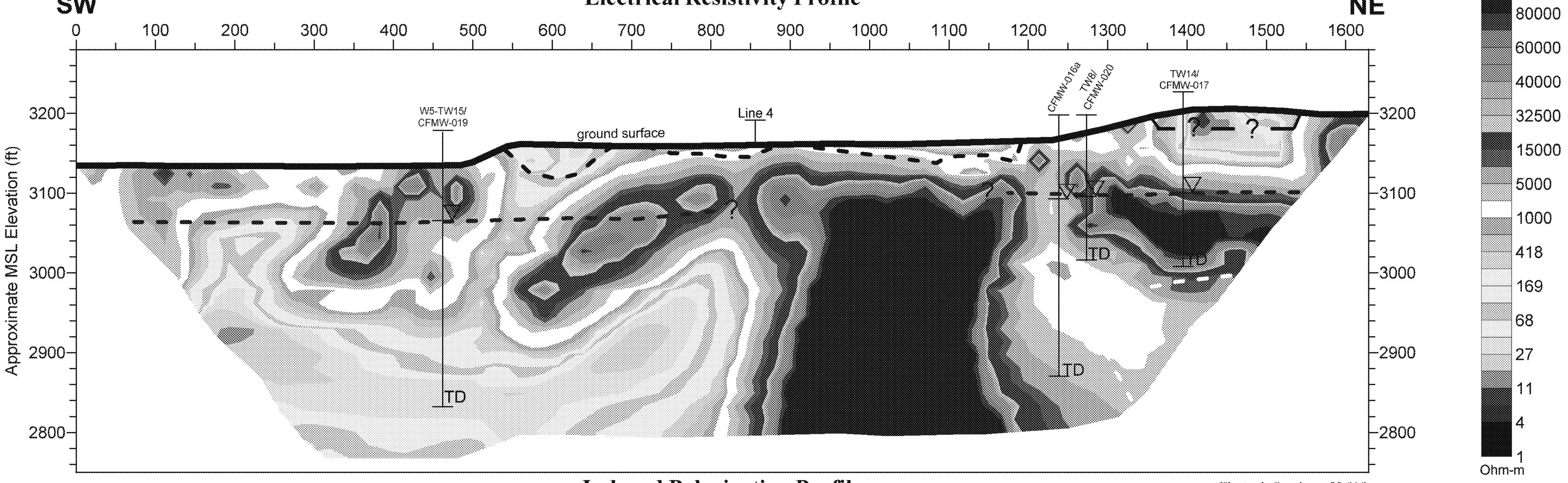
Electrical Resistivity and Induced Polarization Profile - Line 4	FIGURE NUMBER **5**
PROJECT Geophysical Investigation 2000 Aluminum Drive Columbia Falls, Montana	
PREPARED FOR Roux Associates Islandia, New York	PROJECT NUMBER 1604181L
SCALE 1 inch = 150 feet; FIGURE BY BAU; REVIEWED BY LCD	DATE 7/20/16

ED_002345B_00009369-00026

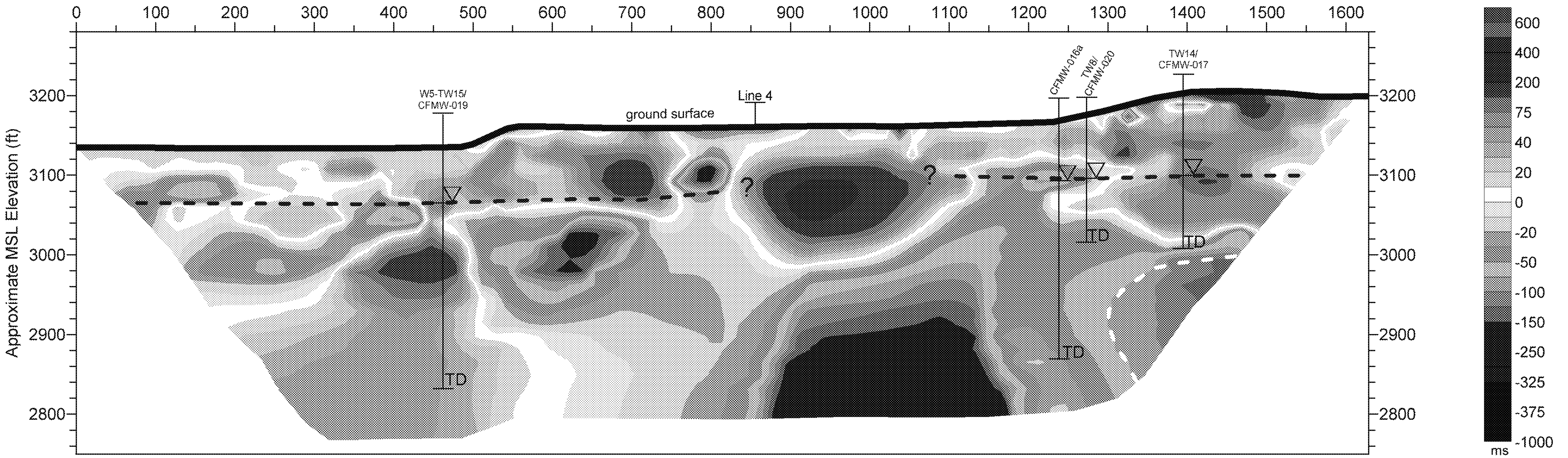
Line 5

Electrical Resistivity Profile



Electrode Spacing = 32.81ft

Induced Polarization Profile



Electrode Spacing = 32.81ft

Water Table
TD Total depth of boring
BD Depth to Bedrock from drilling results

Interpreted Base of Landfill Material
Interpreted elevation of groundwater, queried where uncertain
? ? Expected base of landfill material
Interpreted Top of Bedrock

scale in feet
0 75 150

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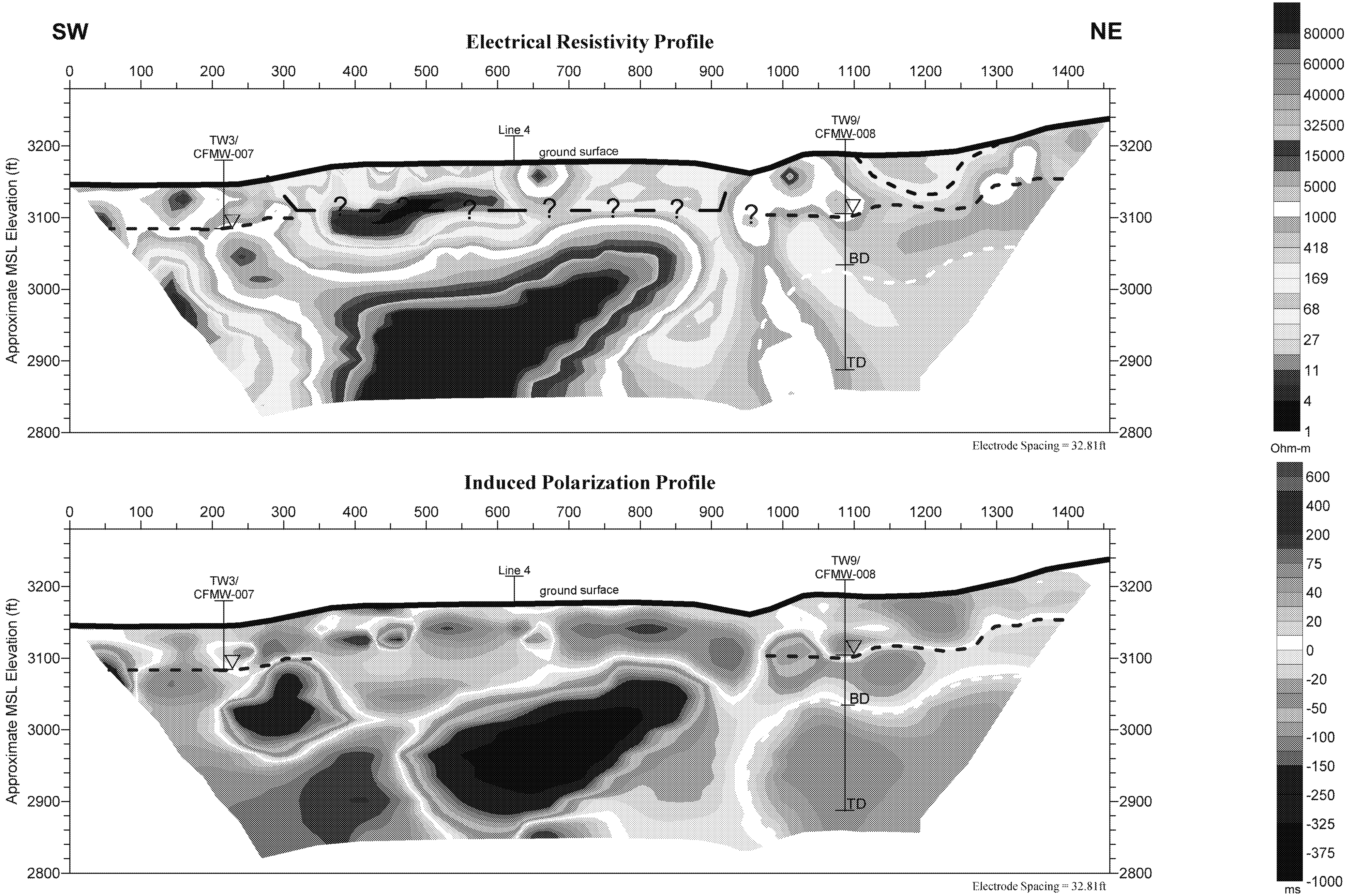
Electrical Resistivity and Induced Polarization Profile - Line 5	FIGURE NUMBER 6
PROJECT Geophysical Investigation 2000 Aluminum Drive Columbia Falls, Montana	
PREPARED FOR Roux Associates Islandia, New York	PROJECT NUMBER 1604181L
SCALE 1 inch = 150 feet; FIGURE BY BAU; REVIEWED BY LCD	DATE 7/20/16

Line 6



Legend

- Water Table
- TD — Total depth of boring
- BD — Depth to Bedrock from drilling results
- Interpreted Base of Landfill Material
- Interpreted elevation of groundwater, queried where uncertain
- Expected base of landfill material
- Interpreted Top of Bedrock

scale in feet
0 75 150

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Electrical Resistivity and Induced Polarization Profile - Line 6			FIGURE NUMBER **7**
PROJECT Geophysical Investigation 2000 Aluminum Drive Columbia Falls, Montana			
PREPARED FOR Roux Associates Islandia, New York			PROJECT NUMBER 1604181L
SCALE 1 inch = 150 feet	FIGURE BY BAU	REVIEWED BY LCD	DATE 7/20/16